ARS 72-19
January 1961

INVESTIGATIONS ON THE MODIFICATIONS OF YARN AND FABRIC STRUCTURE NEEDED TO IMPROVE TEAR STRENGTH OF COTTON FABRICS

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

INVESTIGATIONS ON THE MODIFICATIONS OF YARN AND FABRIC STRUCTURE NEEDED TO IMPROVE TEAR STRENGTH OF COTTON FABRICS[1]

by

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INTRODUCTION

In the initial phase of this research concerning improvement in tear strength of cotton fabrics, a group of 10 resin-treated cotton fabrics, representative of a large variety of fabric types and weights, were obtained from commercial sources. Each sample of resin-treated cotton fabric was accompanied by its unresinated counterpart, normally referred to as the "prepared" fabric. In addition to samples in the "prepared" and resinated states, samples following each stage of finishing were obtained. This was deemed pertinent to the goal of the research to determine the history of tear characteristics of cotton fabric as it passed through the progressive stages of finishing. Accordingly, wherever possible, samples representative of the fabric in the greige, desized, scoured, bleached and dyed, and resin-finished state were procured.

The analysis of the change in tear performance after each wet processing treatment pointed out quite clearly that generally the cotton fabric had lost the greater portion of its greige fabric tear strength prior to the resin treatment. For the fabrics examined in Part I of the subject contract (phase one of the study), the severest decreases in tear strength appeared to be the result of the scouring process. The effect of resin treatment on the tear characteristics was not consistent.

Following completion of the work of Part I of the subject contract, 4 fabric constructions from among the 10 commercial fabrics studied were selected for the projected studies that were outlined in Parts III and IV.

For this present phase report, bearing in the main on phases two and three of the subject contract (of Part II), a more detailed analysis is presented of the effects of resin treatment on properties of cotton fabric pertinent to tear. The purpose was to delineate, where possible, the principal factors contributing to the change in tear properties of the fabric occasioned by treatment with resin. The twofold study was made to determine the modifications in yarn and fabric structures necessary to obtain improved tear strength. First was a consideration of certain theoretical aspects of the mechanics of tear as they relate to yarn or fabric geometric parameters pertinent to tear strength and an analysis of the tear diagrams of the samples studied in Part I. The second part of the study was an investigation of the effects on tear strength of certain variations found in yarn and fabric structures of 23 fabrics from an earlier investigation.

Based on the findings of the above studies, a series of 28 experimental fabrics were designed (phase four, also of Part II) as variations on the 4 constructions that had been selected for future study (Parts III and IV). The details of the yarn and fabric constructions for these 32 experimental fabrics are submitted herein.

CHANGES IN YARN AND FABRIC PROPERTIES OCCASIONED BY RESIN

The work concerning Part 1 (Phase Report No. 1)[2] demonstrated that the effect of commercial resin treatment on tear strength is not universally a deleterious one. Four of the six

[1] A report of work done by Fabric Research Laboratories, Inc., under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract is being supervised by the Southern Utilization Research and Development Division of the Agricultural Research Service.

[2] ARS 72-18 "Investigation of the Effect of Preparatory Finishing, Processing and Resin Treatment on the Tear Strength of Various Commercial Cotton Fabrics."

Table 1.—*Comparison of some physical properties of samples that manifested more than 10% relative change in tear strength after resin treatment*

Sample No.	Decrease[1] in Pu	Yarn strength[2]			Threads per peak			Monsanto crease angle			Yarn crimp			
											D		E	
		D	E[3]	Decrease[1]	D	E	Decrease[1]	D	E	Increase[1]	Warp	Fill	Warp	Fill
	%	Lb.	Lb.	%	No.	No.	%	Deg.	Deg.	%	%	%	%	%
SAMPLES EXHIBITING LOSS IN TEAR STRENGTH (GROUP A)														
2F	—34.5	0.56	0.31	—44.6	1.48	1.54	+4.1	----	----	----	1.8	25.4	6.4	14.0
3W	—15.2	.66	.47	—28.8	1.43	1.66	+16.1	88	130	47.7	1.9	22.9	2.4	10.7
3F	—35.5	.45	.28	—37.8	1.38	1.31	—5.1	82	131	59.7	----	----	----	----
7F	—26.4	1.26	.85	—32.5	1.35	1.36	+0.7	106	143	34.9	2.6	12.4	2.6	10.3
8F	—27.8	1.60	.95	—40.6	1.14	1.35	+18.4	95	131	37.9	9.0	10.9	7.5	8.1
9F	—45.8	.98	.98	0	1.54	1.20	—22.0	79	137	73.4	7.9	4.3	4.2	9.1
Av.	—30.9	0.92	.64	—30.7	1.39	1.40	+2.0	90	134	50.7	4.6	15.2	4.6	10.4
SAMPLES EXHIBITING GAIN IN TEAR STRENGTH (GROUP B)														
1W	+13.3	0.66	0.62	—6.1	1.39	1.56	+12.2	81	107	32.1	0.7	24.9	1.9	14.3
1F	+19.4	.51	.44	—13.7	1.38	1.40	+1.4	81	102	25.9	----	----	----	----
4W	+16.7	.58	.46	—20.7	1.18	1.54	+30.5	86	141	64.0	1.3	17.2	2.3	9.1
5W	+27.5	.82	.66	—19.5	1.58	1.82	+15.3	67	123	83.6	6.5	3.2	8.4	1.9
6W	+70.0	.57	.49	—14.0	1.51	1.83	+21.2	79	121	53.2	5.1	8.2	7.0	5.9
6F	+40.0	.63	.47	—25.4	1.02	1.46	+43.1	72	112	55.0	----	----	----	----
Av.	+31.2	0.63	0.52	—16.6	1.34	1.60	+20.6	77.6	117.6	52.4	3.4	13.4	4.9	7.8

[1] The percent change for each sample shows the difference between the value for resinated fabric and the value for "prepared" fabric; this difference in each pair of D and E samples is the algebraic average percent of change between the 2 kinds of fabric.

[2] Yarn strength based on average ravel strip tensile divided by threads per inch.

[3] D, Identifies the "prepared" sample; E, identifies the resin treated sample.

warpwise tear results and two of the seven fillingwise tear results indicated improved tear strength (more than 10% increase) as a result of resin treatment. Thus, it can be anticipated that one cannot generally ascribe a single reason to a loss in tear strength that results from resin treatment.

To facilitate an analysis of the changes in yarn and fabric properties as they relate to the concomitant changes in tear performance for the "prepared" and resin-finished fabrics, a tabulation of the yarn strengths, number of threads per peak, Monsanto crease recovery angle, and percent warp and filling crimp is presented (Table 1). Excerpts from this table are interspersed throughout the analysis that follows wherever it was deemed pertinent to the discussion.

A comparison of the data associated with the samples that exhibited improved tear strength in the resin-finished state (Group B) and those samples that were found to have appreciably poorer tear strength following the resin treatment (Group A) reveals some interesting relationships. Of particular interest are the following observations:

a. The scalar magnitude of the percent change in fabric tear strength was approximately the same for both sets of fabrics.

b. Both sets of fabrics exhibited significant loss in yarn tensile strength following resin treatment. Group A, however, which suffered loss in tear strength, also suffered about twice the average percent of loss in yarn tensile.

Average Percent Change In—		
	$\overline{P}_u$	Yarn Strength[3]
Group A	—30.9	—30.7
Group B	+31.2	—16.6

c. In the "prepared" state the mobility of the yarns in the plane of the fabric, as reflected by the average number of threads rupturing per load drop, is the same for both sets of samples. For resin-treated fabrics, the samples which suffered appreciable losses in tear strength did not change markedly in this property. On the other hand, the group of samples with improved tear strength were all, with the exception of the filling sample, found to have considerably improved mobility.

Average Number of Threads per Peak			
	Prepared	Resinated	% Change[3]
Group A—	1.39	1.40	+2.0
Group B—	1.34	1.60	+20.6

d. The percent improvement in Monsanto crease recovery angle resulting from the application of resin was found to be essentially the same for both groups of samples. Of considerable interest in this regard is the fact that the average level of Monsanto crease recovery angle among the samples that lost tear resistance in the resinated state is significantly higher than that of the group which manifested superior tear strength in the resinated state.

Average Monsanto Crease Recovery Angle			
	Prepared	Resinated	% Change[3]
Group A—	90°	134°	50.7
Group B—	77.6°	117.6°	52.4

e. Despite the seeming similarity in the level of warp and filling crimp in the "prepared" and finished state for both sets of samples, there is a consistency in the crimp interchange, see Table 1 (warp crimp increases—filling crimp decreases) among the samples with improved tear strength that is not found among the samples with decreased tear strength. Of particular interest in this consideration of the effect on tear strength of crimp and crimp interchange is the change in warp and filling crimps in sample No. 9F. Here there is evidence in resin treating of the fabric of large warpwise tensions that caused the warp crimp to decrease significantly with concomitant doubling of the magnitude of the filling crimp. This particular fabric exhibited the greatest percent loss in tear strength (—45.8), despite an apparent lack of change in yarn tensile strength. There was, however, a large drop in the number of threads breaking per peak. It is possible that the change in filling crimp (the only instance where the filling crimp increased after resin treatment) contributed to the sharp decrease in yarn mobility (—22%) resulting in reduced load-carrying capacity of the del structure.

[3] The % change is based on the algebraic averages of each pair of fabrics, not on the difference between averages.

Certainly the above comments do not represent a definitive statement about any single causal system that resulted in a loss in tear strength for Group A fabrics and an increase in tear strength for Group B fabrics. Nevertheless, some very pertinent relationships are present that do shed some light on the complex interaction of yarn and fabric properties bringing about the observed results. For example:

1. In Group A, where the mobilities of the yarns in the plane of the fabrics are relatively unchanged, the average percent loss in tear strength was kept equal to the average percent loss in yarn strength. From this, one may infer that when other influences are also kept relatively constant yarn strength becomes the dominant factor.

	Average % Change in $\overline{P}_u$	Av. % Change in Yarn Strength	Average Number of Threads per Peak Prepared	Resinated
Group A—	−30.9	−30.7	1.39	1.40

2. All four types of fabric in Group B manifested an identical kind of crimp interchange, i.e., increase in warp crimp accompanied by a decrease in filling crimp. Only two samples (Nos. 2 and 3) of the five fabric types found in Group A exhibited this kind of crimp interchange:

Sample	Average Percent Change Pu	Y. S.	Thds/Peak	Percent Crimp Prepared Warp	Prepared Fill.	Resinated Warp	Resinated Fill.
2F	−34.5	−44.6	+4.1	1.8	25.4	6.3	14.0
3W	−15.2	−28.8	+16.1	1.9	22.9	2.4	10.7

One sample (No. 2) of these fabrics had such an inordinately high loss in yarn tensile that it is doubtful that any single or combination of favorable geometric factors could have mitigated the loss in tear to any significant extent. Concerning the other sample (No. 3), it may be conjectured that the favorable crimp interchange was responsible for the appreciable improvement in warpwise mobility (+16%), which almost certainly mitigated the loss in warp tear that one might expect in a fabric that suffered approximately 30% loss in yarn tensile. Thus, one may venture the conclusion that crimp interchange, resulting from a fillingwise tensioning, tends to enhance the tear characteristics of a fabric.

3. An interesting speculation is the possible effects that the magnitude of crease resistance in the finished fabric may have on its tear strength. The average Monsanto crease recovery value for the finished fabrics in Group A (134°) is significantly higher than that for Group B (117.6°). What would have happened to the tear performance of the samples in Group B if they had been at the same level of crease resistance as Group A? At this time there is no evidence available which can definitely answer that question. It is supposed that higher crease recovery properties in general could result in lower yarn strength, which presumably would produce a decrease in fabric tear strength; however, with the degree of improvement in yarn mobility exhibited by fabrics in Group B this effect would be appreciably mitigated. This latter point leads to the further question: "What effect does the magnitude of crease resistance have on the mobility of the yarns in the plane of the fabric?" If higher crease resistance leads to a restriction of yarn mobility, combined with losses in yarn tensile, the resultant tear strength would undoubtedly be severely decreased. However, there is some evidence available indicating that a restriction of yarn mobility is not a necessary byproduct of good crease resistance. Observe the level of crease resistance in fabric No. 4W, Group B, and the concomitant change in yarn mobility as shown in Table 1. This sample exhibited a 30% increase in yarn mobility upon resination, at which stage it was found to have a Monsanto crease recovery angle of 141°. Thus, it would seem that fabrics with excellent crease recovery can have very good yarn mobility in the plane of the fabric. It is believed that this beneficial combination of high crease recovery and good yarn mobility is attained primarily by good finishing techniques, and is a function of yarn or fabric geometry only secondarily. Nevertheless, the role of yarn or fabric geometry in determining the tear properties of cotton fabrics must not be overlooked.

EFFECT ON TEAR STRENGTH OF VARIATIONS IN YARN AND FABRIC GEOMETRY

The foregoing discussion was almost exclusively qualitative in nature, of necessity since the complete mechanism of the tearing action is not known, and whatever portion is known must be described principally in general terms. Additionally, a sufficient number of anomalous results have been encountered that serve to point up the real need for a more thorough comprehension of the mechanism of tear.

It seems appropriate at this point to discuss just what is known of the mechanism of tear. What remains to be discovered and how we may proceed in the research in the light of what is known and can be learned from additional empirical investigation will be considered later in this section.

Theory of Geometric Parameters As Influencing Tear Strength

First let us review and consider what is known about the mechanics of the tearing action. Krook and Fox,[4] indicated photographically that the cross yarns fail in tension during the tongue-tear and that the tearing action was a result of progressive tensile failure of these cross yarns rather than any shearing action perpendicular to the surface of the fabric. They also observed a hyperbolic curvature in the sides of the del (the alleged active region of tear), that was subsequently confirmed by observations made at these laboratories by Teixeira, Platt, and Hamburger.[5]

In their work on the relation of certain geometric factors to the tear strength of woven fabric, Teixeira et al.,[5] showed that the load-elongation diagram of the del may be synthesized, for a hypothetical fabric, from a knowledge of the load-elongation diagram of the cross yarns and their arrangement in the del. Their theoretical considerations, both graphical and mathematical, of the load-elongation diagram of the del structure pointed out an important aspect of the arrangement of yarns in the del, namely: It is more important that the yarns in the del have narrow interyarn spacing than that there be more yarns in the del. Favorable proximity of the yarns enhance the elongation balance among the yarns, which in turn results in an increased load-carrying capacity for the del structure. Thus, the shape of the load-elongation diagram of the del yarns, their ultimate elongation, and the variability of their ultimate elongation, all contributing to elongation balance, are important factors in the development of the tear strength properties of any woven fabric. This hypothesis appears to be confirmed by the analyses of the tear diagrams of the samples studied, relative to Part I, showing that increases in the average number of yarns rupturing per load drop resulted in raising the average level of tear strength.

Through the expedient of representing those fabric components that are under load during the tearing action by a mechanical model consisting of springs arranged in series and in parallel (Figure 1, a), Teixeira et al. were able to construct a graphical presentation of the interaction between yarns in the del, fabric in parallel with the del, and the tails, during a hypothetical tearing action involving only two del yarns. This presentation is found in Figure 1, b.

Several important relationships were observed in considering this graph, and some pertinent inferences were made. For example, the extent of tail contraction is seen to be a function of the spring constant of the tails. Furthermore, one could expect that if the tensile rigidity of the tails decreased markedly, the amount of tail contraction could exceed the difference in ultimate elongation levels of the mechanically conditioned del yarns, so that both yarns would rupture before a new equilibrium point was attained. It is also possible to determine from this diagram the

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[4] Krook, C. I. and Fox, K. R. "Study of the Tongue Tear Test," Textile Res. Jour. 15: 389-402. (1945)

[5] Teixeira, N. A., Platt, M. M., and Hamburger, W. J., "Mechanics of Elastic Performance of Textile Materials, Part XII: Relation of Certain Geometric Factors to the Tear Strength of Woven Fabrics," Textile Res. Jour. 25: 838-861. (1955)

Figure 1, a—*Mechanical Representation of Tongue-Tear Specimen.* Figure 1, b—*Graphical Presentation of Spring System.*

Figure 1b. Graphical Presentation of Spring System

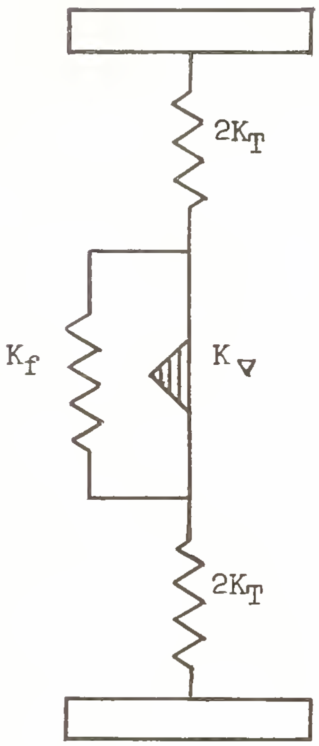
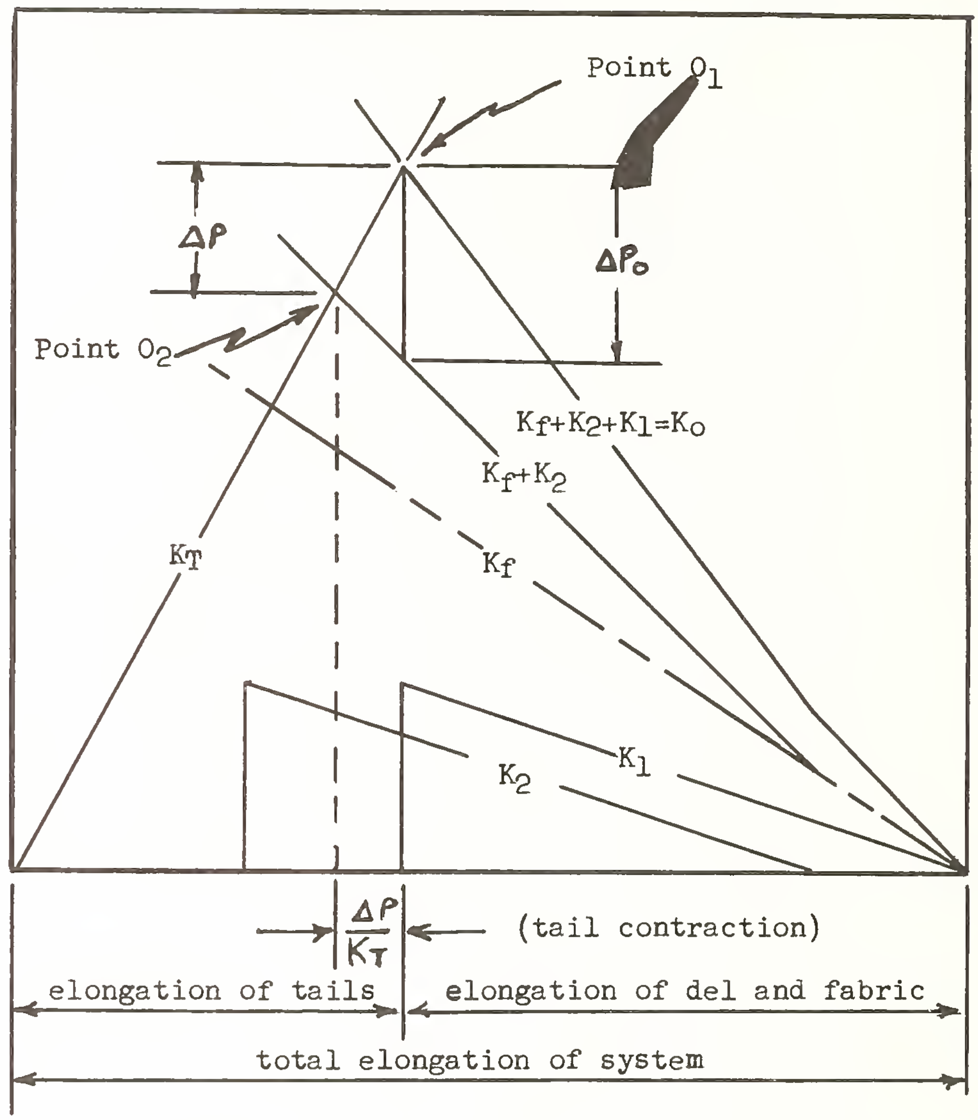


Figure 1a. Mechanical Representation of Tongue-Tear Specimen



K = Effective spring constant of specimen being held

$2K_T$ = Spring constant of one of the tails; K_∇ = Effective Spring Constant of the del

K_f = Effective spring constant of the fabric being loaded in parallel with del.

$K_o = K_f+K_\nabla$ is spring constant of specimen if tails are of zero length

According to rule for series springs:

$$1/K = (1/K_o) + (1/2K_T) + (1/2K_T) = (1/K_o) + (1/K_T)$$

$$K = (K_oK_T)/(K_o+K_T)$$

For every load that is placed on the series combination of K_T+K_o there is an equillibrium position which may be determined graphically as shown in Figure 1b.

K_1 and K_2 are slopes of mechanically conditioned del yarns.

ΔP = load drop at the jaws

ΔP_o = load drop which would occur if tails were of infinite stiffness

Equillibrium points - O_1 before K_1 breaks; O_2 after K_1 breaks

ratio of the load drop on the whole system, ΔP, to the drop in load carrying capacity of K_o or ΔP_o. Neglecting K_f, ΔP_o (which is the load drop that would occur at the jaws if the tails were of infinite tensile stiffness) would be equal to the breaking strength of the yarn ruptured in the del. It has been shown[4] that ΔP_o is always greater than the breaking strength of the del yarn and that this is due in large part to a discontinuity in the loading of K_f. The difference (ΔP_o -yarn breaking strength) is a measure, therefore, of how much load K_f is supporting just before the del yarns break. It has also been shown[5] —and generally confirmed by the studies discussed in the second part in this section—that in looser, more distortable fabrics the value of (ΔP_o -yarn breaking strength) becomes larger. Therefore, it is not especially surprising that the expression for ΔP_o, which may be derived from the graph in Figure 1, b,

$$\Delta P_o = \Delta P \left(\frac{K_V}{\overline{K}_T} + \frac{K_f}{\overline{K}_T} + 1 \right),$$

shows that the amount of fabric assistance depends upon the relative extensibilities of the tails and the fabric loaded in parallel with the del.

Thus, the factors in fabric geometry that influence the shape of the del and the nature of the fabric structure in parallel with the del are seen to affect not only the load capacity of the del but also the amount of assistance rendered by the untorn fabric.

Unfortunately, there are a number of unknowns in the mechanics of tear that present obstacles to any complete quantitative synthesis of the tearing action. Perhaps the most important of these is the action of the fabrics loaded in parallel with the del, represented above as K_f. Were it not for this component, the tear load diagram could be completely synthesized from the yarn characteristics, the yarn spacing, and the spring constant of the tails. However, inasmuch as the parallel loaded fabric is an important factor contributing to the tear characteristics of a fabric, and information about its performance is in general lacking, the desired synthesis cannot be completed. Another serious unknown is the effective gage length of the yarns under tension in the del. This of course determines the level of breaking strength of the del yarns, which in the case of nonuniform yarns, may be considerably different from strengths obtained at standard test lengths.

Still other factors that remain obscure are such geometrical factors as alinement of the del structure relative to the direction of the tear force; load level and extent to which the yarns in the del were mechanically conditioned, prior to becoming del yarns, by the action of the discontinuous loading on the del and on the fabric in parallel with the del; and effect of bending the del yarns around the orthogonal set of yarns forming the hyperbolically shaped pseudojaws. The scope of this research project does not encompass the determination of these factors.

Effects of Geometry Changes on Tear Strength

Despite the above-mentioned gaps in knowledge bearing on the yet theoretical aspects of tear, there exists a substantial deposit of general knowledge pertinent to the goal of this research that is a good basis for any empirical investigation of the effects on tear strength of variations in yarn and fabric geometry. Thus, an awareness that such factors as the following affect tear strength will certainly be helpful in the design of fabrics for any future studies to be undertaken: The amount and type of distortion at or near the del; the relative extensibility of the fabric loaded in parallel with the del; the shape of the load-elongation curve of the mechanically conditioned del yarn, its breaking strength, ultimate elongation and variability of ultimate elongation; and the extensibility of the fabric which transmits the load to the del.

It seemed appropriate therefore, to attempt to measure the degree to which changes in yarn and fabric geometry effected changes in the tear properties of cotton fabrics. Such a study was made possible by the availability in the current research of a pedigreed series of 23 cotton fabrics designed and produced for research conducted for the United States Department of Agriculture under an earlier contract (Number A-ls-33979) entitled: "Research to Improve the Draping Properties of Cotton Fabrics by Varying Yarn and Fabric Struc-

tures and Application of Selected Finishing Agents." These fabrics were produced from and identical lot of cotton, Deltapine No. 15, and they were all subjected to the same finishing treatment (desized with enzyme, kierboiled, and chemic-bleached). In general, they each represent a variation of a single yarn or fabric geometric parameter. The details of yarn and fabric structure are listed in Table 2.

The test method (Tongue Tear) has been described in Phase Report No. 1.[2] In this work the average upper peak load has been selected as the criterion of resistance to tear. The data obtained in this phase of the research are presented in Table 3.

Table 2.—*Geometric parameters varied in United States Department of Agriculture experimental fabrics*

[Dashes indicate parameters the same as that of control fabric]

Sample No.	Threads per inch		Yarn size		Twist multiplier		Weave
	Warp	Filling	Warp	Filling	Warp	Filling	
1 (Control)	64	64	30/1	30/1	4.0 Z	4.0 Z	Plain
2	----	48	--------	--------	--------	--------	--------
2A	----	48	--------	18/1	--------	--------	--------
3	----	80	--------	--------	--------	--------	--------
3A	----	80	--------	42/1	--------	--------	--------
4	----	----	--------	--------	--------	4.0 S	--------
5	----	----	--------	--------	--------	3.0 Z	--------
6	----	----	--------	--------	--------	3.5 Z	--------
7	----	----	--------	--------	--------	4.5 Z	--------
8	----	----	--------	--------	--------	5.0 Z	--------
9	----	----	--------	--------	--------	--------	2/1 Twill
10	----	----	--------	--------	--------	--------	2/2 Twill
11	----	----	--------	--------	--------	--------	3/1 Twill
12	----	----	--------	--------	--------	--------	2X2 Basket
13	----	----	--------	--------	--------	--------	Oxford
14	----	----	18/1	18/1	--------	--------	--------
15	----	----	18/1	--------	--------	--------	--------
16	----	----	18/1	18/1	--------	--------	3/1 Twill
17	----	----	18/1	18/1	--------	--------	Oxford
18	----	----	42/1	42/1	--------	--------	--------
19	----	----	42/1	--------	--------	--------	--------
20	----	----	42/1	42/1	--------	--------	3/1 Twill
21	----	----	42/1	42/1	--------	--------	Oxford

Table 3.—*Effect of geometric variables on tear strength and other properties pertinent to tear strength of cotton fabrics*

Sample No.	Principal variable [1]	Av. upper Peak		Av. threads per peak		Yarn strength [2] in fabric		Crimp	
		Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
	A. Yarn size:	*Pounds*	*Pounds*	*Number*	*Number*	*Pounds*	*Pounds*	*Percent*	*Percent*
14	18/1 Warp, and Filling	2.71	2.88	1.12	1.14	1.23	1.32	6.3	11.7
1	30/1 Warp and Filling	1.62	1.74	1.05	1.16	.70	.70	2.3	11.4
18	42/1 Warp and Filling	1.24	1.42	1.01	1.04	.47	.46	.8	9.2
15	18/1 Warp, 30/1 Filling	2.85	1.67	1.03	1.04	1.25	.72	4.1	11.3
19	42/1 Warp, 30/1 Filling	1.25	1.81	1.05	1.09	.50	.72	1.7	9.5
	B. Fabric weave:								
1	Plain	1.62	1.74	1.05	1.16	.70	.70	2.3	11.4
13	Oxford	3.30	3.05	1.99	1.30	.62	.67	.9	9.6
9	Twill 2/1	2.05	2.29	1.03	1.14	.72	.65	1.9	8.1
10	Twill 2/2	2.54	2.77	1.09	1.30	.67	.59	1.0	9.2
12	2/2 Basket	5.14	5.16	1.61	1.98	.67	.62	1.0	8.5
11	Twill 3/1	2.76	3.14	1.11	1.33	.68	.63	1.0	8.6
	C. Fabric texture:								
2	64x48	1.78	1.60	1.02	1.05	.68	.62	2.0	8.2
1	64x64	1.62	1.74	1.05	1.16	.70	.70	2.3	11.4
3	64x80	1.64	1.83	1.04	1.11	.69	.72	2.8	11.0
2A	64x48 (30/1 W, 18/1 F)	1.69	2.59	1.04	1.06	.73	1.05	3.4	8.0
3A	64x80 (30/1 W, 42/1 F)	1.60	1.35	1.04	1.15	.71	.49	1.2	11.9
	D. Weave and yarn size:								
14	18/1 W. & F., Plain	2.71	2.88	1.12	1.14	1.23	1.32	6.3	11.7
17	18/1 W. & F., Oxford	5.03	3.90	1.91	1.27	1.15	1.24	1.6	11.3
16	18/1 W. & F., Twill 3/1	3.52	4.07	1.10	1.16	1.22	1.18	2.4	8.6
18	42/1 W. & F., Plain	1.24	1.42	1.01	1.04	.47	.46	.8	9.2
21	42/1 W. & F., Oxford	2.77	2.60	1.37	1.00	.41	.42	.9	10.4
20	42/1 W. & F., Twill 3/1	2.49	2.92	1.33	1.10	.42	.39	.7	7.1
	E. Filling twist multiplier								
4	4.0 S	1.67	1.81	1.03	1.16	.70	.70	2.4	9.8
5	3.0 Z	1.71	1.83	1.03	1.08	.71	.66	2.0	9.6
6	3.5 Z	1.61	1.84	1.04	1.18	.73	.68	2.5	10.3
7	4.5 Z	1.60	1.65	1.03	1.04	.68	.70	3.0	9.0
8	5.0 Z	1.62	1.79	1.06	1.09	.74	.68	2.6	9.3

[1] The principal variable refers to the extent of principal difference from the Control Fabric (No. 1).
[2] Obtained by dividing the Ravel Strip tensile strength by threads per inch.

Note—Control Fabric Construction:
Threads/inch, 64x64.
Yarn size, 30/1 W. & F.
Filling twist multiplier, 4.0 Z.
Weave, plain.

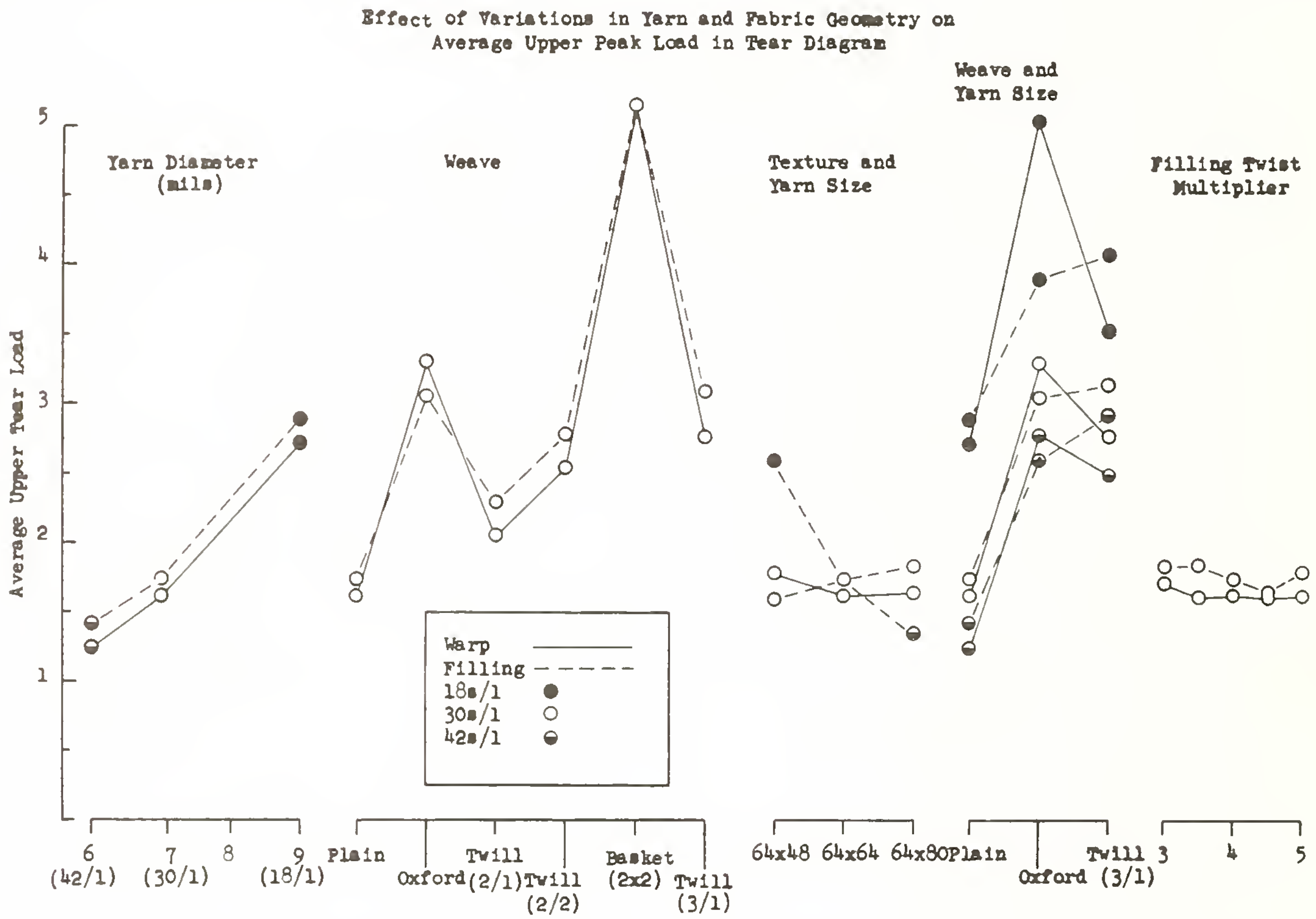
A schematic representation of the effect on tear strength of the yarn and fabric variables examined in this study is found in Figure 2.

It is immediately apparent, from an examination of Figure 2, that the most significant increases in tear strength have been occasioned by either the incorporation of heavier yarns (in one or both systems of yarns) or by varying the weave. In the latter category, the 2 x 2 basket weave manifests quite a dramatic improvement in both the warp and filling tear resistance. Based on the initial studies and the theoretical considerations just discussed, these are not unexpected results.

It has been shown both empirically and theoretically that when other factors are relatively unchanged the strength of the yarn in the del becomes the dominant influence on the tear strength of the fabric. In this series of fabrics a set of three fabrics, which were alike in the number of threads per inch, yarn twist, fabric weave, and finishing treatment exhibited improved tear strength as the yarn size was increased in warp and filling.

Sample No.	18	1	14
Yarn size[1]			
Warp	42/1	30/1	18/1
Filling	42/1	30/1	18/1
Av. upper peak load (lb.)			
Warp	1.24	1.62	2.71
Filling	1.42	1.74	2.88

Figure 2.—*Effect of variations in yarn and fabric geometry on average upper peak load in tear diagram.*



It has also been demonstrated, again both empirically and theoretically, that the closer the yarns are spaced in the del the more desirable the elongation balance will be with respect to the load-carrying capacity of the del structure. This is reflected in the tear test measurements as an increase in the number of threads breaking per peak. Additionally, the amount of distortability in the plane of the fabric ahead of the del will lead to trellising and result in greater fabric assistance. Both characteristics are reflected by the majority of fabrics using

[1] Other yarn and fabric geometric details than yarn size and crimp are the same as the control fabric, No. 1. See Table 3.

fancy weaves; and, as one would anticipate from its nature, the 2 x 2 basket-weave construction exhibited the most outstanding improvement in tear strength by a change in a single geometric parameter. It is interesting to note that certain of the fancy weave fabrics do not manifest an increase in the number of yarns breaking per peak. Thus one may infer that all of the increase in tear strength is due to distortability in the plane of the fabric in the region ahead of the del, which permits trellising, thereby magnifying the extent and influence of fabric assistance on the tear strength. A comparison of the tear data for Samples Nos. 1 and 9, and Samples Nos. 14 and 16, will illustrate this point.

	1	9	14	16
Sample No. and Weave [1]	Plain	Twill 2/1	Plain	Twill 3/1
Warp	30/1	30/1	18/1	18/1
Filling	30/1	30/1	18/1	18/1
Av. upper peak load (lb.)				
Warp	1.62	2.05	2.71	3.52
Filling	1.74	2.29	2.88	4.07
Number of threads per peak				
Warp	1.05	1.03	1.12	1.10
Filling	1.16	1.14	1.14	1.16

[1] Other yarn and fabric geometric details than weave, crimp, and yarn size are the same as the control fabric, No. 1. See Table 3.

The above data tend to corroborate the hypothesis, postulated earlier in discussing the theoretical aspects of the mechanics of tear, that the difference (ΔP_o —yarn breaking strength) is a good measure of how much load was supported by the fabric in parallel with the del. Since the yarn breaking strengths for sample fabrics Nos. 1 and 9 were alike, also those for Nos. 14 and 16, for each pair the magnitude of the ration of ΔP_o twill to ΔP_o plain weave would give some indication as to how the fabric assistance rendered by the twill fabrics exceeded that of the plain weave. For sample fabrics Nos. 1 and 9, the ratio ΔP_o twill to ΔP_o plain was 1.6:1, and for Nos. 14 and 16 it was 1.4:1. The conclusion that the fabric assistance afforded by the twill exceeds that of the plain weave can also be validated by differences in the lower peak loads (P_m).

No appreciable change in tear strength is apparent among the samples that varied only in filling twist multiplier. This is also true for the fabrics that varied fabric texture by changing the number of picks per inch from 48 to 80 (Sample Nos. 2 and 3).

Sample No.	2	3
Threads per inch [1]		
Warp	64	64
Filling	48	80
Av. upper peak load (lb.)		
Warp	1.78	1.64
Filling	1.60	1.83

[1] Other yarn and fabric geometric details than number of threads per inch are the same as the control fabric, No. 1. See Table 3.

On the basis of results observed in related work in other projects, and of pertinent theoretical considerations indicating that lower cover factors enhance fabric tear strength, it is quite surprising to find that two fabric constructions as dissimilar as (64 x 48) and (64 x 80) do not manifest larger differences in tear characteristics. Nevertheless, the differences are considered statistically significant at the 95% probability level. In other words, one can say that the increase in warp tear and the decrease in filling tear exhibited by sample No. 2 in comparison with the corresponding values of sample No. 3 could happen by chance, on the average, only 5 times in 100. Thus, it is reasonable to conclude that this difference in tear strength can be attributed to variations in geometry and not to variations ascribed to change. It is possible that these constructions represent an insensitive range of texture within which any variation in texture is insufficient to alone effect large changes in tear strength. Our experience, however, has shown that fabrics in a more open texture as well as in a near jammed state do exhibit significant changes in tear strength when appropriate variations in texture are introduced. A fabric at the jammed state, then, would be expected to manifest an improved tear strength when the number of threads per inch in the yarns parallel to the direction of tear is reduced. Conversely, an increase in the threads per inch of the yarns parallel to the direction of tear, in the case of an open textured fabric, would be expected to result in a decrease in tear strength.

Of great interest in this study are the excellent results obtained by varying two geometric parameters in a single fabric. Witness the level of tear strength exhibited by a fabric woven

with 42/1 yarns in an oxford weave (sample No. 21) relative to that of a plain weave fabricated with 18/1 yarns (sample No. 14):

Sample No. and Weave [1]	14 **Plain**	21 **Oxford**
Yarn Size		
Warp	18/1	42/1
Filling	18/1	42/1
Av. upper peak load (lb.)		
Warp	2.71	2.77
Filling	2.88	2.60

[1] Other yarn and fabric geometric details than weave and crimp are the same as the control fabric, No. 1. See Table 3.

Although the tear strengths of these two samples are equivalent, the relative weight of sample No. 14 is more than double that of sample No. 21 and the average strength of its 18/1 yarn is more than 250% greater than that of the 42/1 yarn. In this example the advantage of high yarn strength is significantly diminished by the higher relative cover factor (more than 50%) in sample No. 14, together with the limited distortability of its plain weave. On the other hand the lower cover factor and high distortability of the oxford weave sample No. 21 overcame its yarn strength deficit.

Another example of combining variables to achieve improved tear strength, in this instance without notable changes in either relative weight or relative cover factor, is found in the comparison of sample fabrics Nos. 2A and 3, wherein the number of picks per inch was reduced from 80 to 48, and the filling yarn size increased from 30/1 to 18/1. The relative weights of the two fabrics are alike and sample No. 2A has a slightly lower relative cover factor fillingwise. The fillingwise tear was increased by 41.5%.

Sample No.	2A	3
Threads per inch [1]		
Warp	64	64
Filling	48	80
Yarn Size		
Warp	30/1	30/1
Filling	18/1	30/1
Av. upper peak load (lb.)		
Warp	1.69	1.64
Filling	2.59	1.83

[1] Other yarn and fabric geometric details than texture, crimp, and yarn size are the same. See Table 3.

To summarize briefly the salient features of this study of the effect on tear strength of variations in yarn and fabric geometry, it suffices to say that there are two effective means available to the textile technologist who desires to modify a fabric structure in a manner that will improve its tear strength properties. These are: (1) Utilization of appropriate weaves and textures that will enhance the mobility of the yarns in the del and distortability of the fabric in parallel with the del, and (2) the use of yarns having, by virtue of their size, construction, or preparation, more desirable tensile properties.

SELECTION OF FOUR FABRIC CONSTRUCTIONS FOR STUDY IN PARTS III AND IV

Four commercial fabric constructions were chosen from among the 10 studied relative to Part I of the subject contract. The four were selected as a basis for 28 modifications, the 32 fabrics to be studied as outlined in Parts III and IV. The four fabrics represent a wide range of fabric weight, texture, and weave, and it was generally agreed that they were typical of the cotton fabrics that are produced in large quantities and are normally resin treated. One fabric is a lightweight print cloth (85 x 76 threads per inch) identified as sample No. 1 in the test data of Part I (Phase Report No. 1); a second fabric, sample No. 6 also of the Part I studies, is classified as a broadcloth, (139 x 69); a third fabric, sample No. 7, is a sateen work clothing fabric; and the fourth fabric, sample No. 8, is a 3/1 twill cloth representing the heavy weight fabrics (8.3 oz./sq. yd.).

The last two fabrics (sateen and 3/1 twill) manifested losses in tear strength owing to resin treatment in the order of 27%, but the commercial samples of print and broadcloth exhibited higher values of tear strength in the commercially resinated state than they did in the prepared state. However, the print

cloth, which had been labeled as a "wash and wear" fabric had very poor crease resistance (107° warp, 102° filling). When this fabric was resin treated by the contractor, the resulting crease recovery was 136° warp, 132° filling; and at this level of crease resistance the fabric exhibited losses in tear (21.2% warp, and 36.1% filling) where it had formerly been found to have approximately 14 to 19% better tear after resin treatment. In the case of the broadcloth, it was found to have fair crease resistance (121° warp, 112° filling); and at these values the fabric, commercially resin treated, manifested very significant increases in tear (about 70% in warpwise tear and 50% fillingwise). This fabric was also resin treated by the contractor, and at the new levels of crease resistance (129° warp, 123° filling) it continued to manifest excellent tear characteristics compared with those shown in the prepared state (24.1% increase in tear strength warpwise and no change in tear fillingwise). In view of this rather extraordinary performance, it seemed very pertinent to this research on tear to include this fabric among the four selected.

Table 4—*Variations to be manufactured in yarn and fabric geometry from 4 basic fabric constructions selected for study in Parts III and IV*

Warp, control, and variation	Threads per inch				Yarn size		Fabric weave
	Off loom		Finished				
	Warp	Filling	Warp	Filling	Warp	Filling	
Warp No. 1 Control 1	79	78	85	76	30/1	40/1	Plain
Variation (a)	79	78	85	76	30/1	40/1 [1]	Plain
" (b)	79	68	85	66	30/1	30/1	Plain
" (c)	79	60	85	57	30/1	30/1	Plain
" (d)	79	60	85	57	30/1	30/1	2x2 Basket
" (e)	79	68	85	66	30/1	30/1	2x2 Basket
" (f)	79	78	85	76	30/1	40/1	2x2 Basket
" (g)	75	82	80	80	30/1	40/1	2x2 Basket
" (h)	75	82	80	80	30/1	40/1	Plain
Warp No. 2 Control 2	135	70	139	69	48/1	48/1	Plain
Variation (a)	135	70	139	69	48/1	48/1 [1]	Plain
" (b)	135	70	139	69	48/1	48/1	3/1 Twill
" (c)	135	70	139	69	48/1	48/1	Oxford
" (d)	135	64	139	62	48/1	40/1	Plain
" (e)	135	60	139	57	48/1	40/1	Plain
" (f)	135	60	139	57	48/1	40/1	Oxford
Warp No. 3 Control 3	125	56	130	54	22/1	15/1	Sateen [2]
Variation (a)	125	56	130	54	22/1	15/1 [1]	Sateen [2]
" (b)	125	56	130	54	22/1	15/1	Oxford
" (c)	120	58	125	55	22/1	15/1	Sateen [2]
" (d)	120	52	125	50	22/1	15/1	Sateen [2]
" (e)	120	52	125	50	22/1	15/1	Oxford
Warp No. 4 Control 4	110	58	116	55	15/1	15/1	3/1 Twill
Variation (a)	110	58	116	55	15/1	15/1 [1]	3/1 Twill
" (b)	110	58	116	55	15/1	15/1	Oxford
" (c)	105	58	110	55	15/1	15/1	3/1 Twill
" (d)	105	52	110	50	15/1	15/1	3/1 Twill
" (e)	105	58	110	55	15/1	15/1	Oxford
" (f)	105	52	110	50	15/1	15/1	Oxford
Warp No. 5 Control 5 [3]	95	58	100	55	14/1	15/1	3/1 Twill
Variation (a)	95	58	100	55	14/1	15/1 [1]	3/1 Twill
" (b)	95	58	100	55	14/1	15/1	Oxford

[1] Filling twist direction is "S", all other yarns are "Z" twist.
[2] 5 harness sateen.
[3] Warp No. 5 is a variation of control fabric No. 4.

DESIGN OF 28 EXPERIMENTAL FABRICS

As a result of the investigation of what changes in yarn and fabric geometry causes changes in tear strength, described earlier in this report, it was apparent that two means were available for improving the tear strength of a fabric by the expedient of altering the yarn or fabric construction. These were:

1. Increase the mobility of the yarns in the plane of the fabric. This may be done by utilizing one or both of the following alterations in fabric geometry:
   (a) use weave with longer floats
   (b) open up the texture of the fabric by decreasing the number of threads per inch.
2. Use a stronger yarn. This normally implies changing to a coarser yarn.

Table 5.—*Percent changes in relative weight and cover factor for USDA tear experimental fabrics*
[Dashes in columns 4-6 indicate samples not different from the control]

Sample	Relative weight [1]	Relative cover factor [2]	Change in total relative weight	Change in relative cover factor	
				Warp	Filling
			Percent	*Percent*	*Percent*
1	2.83-1.90	15.5-12.0	Control	Control	
a	2.83-1.90	15.5-12.0	----	----	----
b	2.83-2.20	15.5-12.0	(+6.3)	----	----
c	2.83-1.90	15.5-10.4	----	----	(—13.3)
d	2.83-1.90	15.5-10.4	----	----	(—13.3)
e	2.83-2.20	15.5-12.0	(+6.3)	----	----
f	2.83-1.90	15.5-12.0	----	----	----
g	2.67-2.00	14.6-12.6	(—1.3)	(—5.8)	(+5)
h	2.67-2.00	14.6-12.6	(—1.3)	(—5.8)	(+5)
2	2.90-1.44	20.0-9.9	Control	Control	
a	2.90-1.44	20.0-9.9	----	----	----
b	2.90-1.44	20.0-9.9	----	----	----
c	2.90-1.44	20.0-9.9	----	----	----
d	2.90-1.55	20.0-9.8	(+2.5)	----	----
e	2.90-1.42	20.0-9.0	----	----	(—9.1)
f	2.90-1.42	20.0-9.0	----	----	(—9.1)
3	5.91-3.60	27.7-13.9	Control	Control	
a	5.91-3.60	27.7-13.9	----	----	----
b	5.91-3.60	27.7-13.9	----	----	----
c	5.68-3.67	26.6-14.2	(—1.7)	(—4)	(+2.1)
d	5.68-3.33	26.6-12.9	(—5.3)	(—4)	(—7.2)
e	5.68-3.33	26.6-12.9	(—5.3)	(—4)	(—7.2)
4	7.73-3.67	29.9-14.2	Control [3]	Control	
a	7.73-3.67	29.9-14.2	----	----	----
b	7.73-3.67	29.9-14.2	----	----	----
c	7.33-3.67	28.4-14.2	(—3.5)	(—5)	----
d	7.33-3.33	28.4-12.9	(—6.5)	(—5)	(—9.1)
e	7.33-3.67	28.4-14.2	(—3.5)	(—5)	----
f	7.33-3.33	28.4-12.9	(—6.5)	(—5)	(—9.1)
5	7.14-3.67	25.8-14.2	(—5.2)	(—13.7)	----
a	7.14-3.67	25.8-14.2	(—5.2)	(—13.7)	----
b	7.14-3.67	25.8-14.2	(—5.2)	(—13.7)	----

[1] Relative weight = threads per inch ÷ yarn count.
[2] Relative cover factor = threads per inch ÷ $\sqrt{\text{count}}$.
[3] Control No. 4 applies to Samples 5,5a, and 5b as well as group No. 4.

In the design of the 28 experimental fabrics, details of which are reported in Table 4, the variations embodied some particular one of the above principles or a combination of them.

The changes in yarn or fabric structure of the sort implied earlier must be made within some frame of reference such that the experimental fabric is related to the control fabric in a reasonable manner. Certainly the level of tear strength of an 80 x 80 print cloth woven with 40s/1 yarns can easily be surpassed by a 2 x 2 basket weave fabric, containing 40 x 40 threads per inch, woven with 12s/1 yarns. The latter represents an increase in relative weight of approximately 66% and a decrease in relative cover factor of 9%. This variation however, could not be construed as bearing any reasonable relationship with the (80 x 80) control fabric. Thus, it was deemed necessary to establish some limits within which the variation for any single construction may act. In the design of the experimental fabrics described herein a maximum tolerance for magnitude of change in weight or cover factor of $\pm 15\%$ was adhered to. In the majority of cases the variations represent no more than a 10% change in either weight or cover factor.

The details of the changes in yarn and fabric geometry are found in Table 4, and the magnitude of the effects of these changes on the relative weight and cover factor of the control fabrics are listed in Table 5. An examination of these tables will show that the predominant source of variation is in the filling direction. There are several excellent reasons for such a selection; one reason is the general experience that the deleterious effect of resin treatment on tear is more severe fillingwise than warpwise; another is the relative ease of producing a well controlled series of experimental fabrics through the expedient of filling changes; and certainly not the least factor to be considered is the inordinate expense of producing the number of warps necessary to give the investigator as wide a range of variables, as it is possible to obtain by variation in the filling.

SUMMARY

Research to determine the modifications of yarn and fabric structures necessary to obtain optimum tear strength and other desirable fabric properties for four fabric constructions, agreed upon by the Contractor and his designated representative, has been completed. This work was accomplished in four phases.

The first phase (Part I of the subject contract) was concerned with a detailed analysis of the resin-treated samples along with their unresinated "prepared" counterparts, and a comparison of the changes in yarn and fabric properties observed in the group of samples that exhibited losses in tear (Group A) with those of the group of fabrics that were found to have improved tear (Group B) in the resin treated state. While this analysis does not define a single causal system to explain the diversity of effects on tear resistance occassioned by resin treatment, it does present several pertinent relationships that appreciably clarify the complex interaction of yarn and fabric properties bringing about the results. One such relationship suggests that the principal determinant of the level of tear strength when other factors are held constant is the strength of the cross yarns. Another relationship shows the ability of a fabric to overcome a deficiency in yarn strength by permitting greater mobility of the yarns in the plane of the fabric. A third relationship suggests that the crimp interchange occasioned by a fillingwise stretching action, namely the increase in warp crimp with a concomitant decrease in filling crimp, will enhance the tear resistance of a fabric. The most encouraging information obtained from this analysis demonstrated the possibility of achieving a considerable degree of fabric crease resistance (140° Monsanto crease angle) with a 20% loss in yarn tensile strength, while still achieving a 16% increase in tear strength.

Part II of the subject contract, considered fully here, includes phases two, three, and four of the research. The second phase is a study of certain theoretical aspects of the mechanics of tear as they relate to yarn or fabric geometric parameters pertinent to improved tear strength. It had earlier been shown,[5] from both a graphical and mechanical synthesis of

the load-elongation diagram of the del structure, that the arrangement of yarns in the del is an important aspect of this structure, the thesis being that it is more beneficial to have narrow interyarn spacing in the del than to have more yarns in the del. It was already known that narrow interyarn spacing results in an improvement in elongation balance among the yarns and a consequent increase in the load-carrying capacity of the del structure.

A belief in the importance of del structure appears to be confirmed by the analyses of the tear diagrams of samples studied in Part I, which demonstrated that increases in the average number of yarns rupturing per peak result in increases in tear strengths of fabrics that manifested no change in yarn strength and very often of fabrics that exhibited losses in yarn strength.

Additional kinds of correlation between inferences from theoretical hypotheses and the observations of empirical data were found in this work. In this instance a consideration of a graphical presentation of the interaction between yarns in the del, fabric in parallel with the del, and the tails, during a hypothetical tearing action involving two yarns led to the following proposition: That the difference between ΔP_0 (the load drop which would occur at the jaws if the tails were of infinite stiffness) and the breaking strength of the del yarns is a measure of the load-carrying capacity of the fabric in parallel with the del. This proposition is confirmed in this work by the performance of fabrics with long floats, and in other studies[5] by the performance of fabrics with open texture compared with those at or near a jammed state.

An investigation of the effects on tear strength of variations in yarn and fabric geometry constituted the third phase of the research. The pertinent findings in this investigation indicated that tear strength of cotton fabrics may be improved by incorporating one or both of the following structural variations: Utilization of weaves with longer floats or of more open-textured fabrics, or both, to increase yarn mobility in the plane of the fabric; by utilization of coarser yarns, stronger fiber, improved preparation, or any combination thereof to increase yarn strength. These results confirm the principal findings of the analysis of the "prepared" and resin treated commercial fabrics of Part I that considered the mechanics of tear, and of the theoretical section of phase two of Part II.

The final phase of the research of Part II was concerned with the designation of certain modifications in the yarn and fabric geometry of the four basic constructions selected from Part I as the control fabrics for the projected studies, outlined in Parts III and IV. These variations in the structure of the control fabrics are predicated on the findings of the three preceding phases. Furthermore, a limitation factor of $\pm 15\%$ was used as the frame of reference within which the modifications of the control fabric would operate. Twenty-eight variations and 4 duplications of the commercial counterpart of the control therefore comprise the 32 experimental fabrics produced by the Southern Utilization Research and Development Division. Details of these experimental fabric constructions are outlined herein.